Reprinted from *1999 Columbia Basin Agricultural Research Annual Report. Spec. Rpt. 999,* pp. 45-48, 1999
Oregon State University in cooperation with USDA-Agricultural Research Service, Pendleton, OR

PREDICTING CARBON SEQUESTRATION IN AGRICULTURAL CROPLAND AND GRASSLAND SOILS

Ron W. Rickman, Clyde L. Douglas, Jr., Stephan L. Albrecht and Jeri L. Berc

Introduction

Atmospheric carbon dioxide (CO_2) concentration has been increasing at an accelerating rate for the past several decades (Keeling and Worf, 1994). Average global air temperature has also risen during the same period (Jones and Briffa, 1992). Certain physical laws indicate that atmospheric CO_2 and global air temperature may be correlated (Doos, 1975). Carbon dioxide is one of the gases known as a greenhouse gas. It permits the transmission of short wavelength radiation (visible and ultraviolet light received from the sun) and inhibits the transmission of long wavelength radiation (infrared or heat radiation that is emitted by the earth) in the same manner that glass does. The end result of this wavelength-dependent transmission of energy is a net storage of heat in the earth's atmosphere, just as heat is stored in a glass-roofed greenhouse on a bright sunny day.

Scientists predict that several processes occurring on the earth may be accelerated or aggravated by increasing the heat load on our atmosphere (Doos, 1975). In addition to increasing air temperature, problems could occur from melting ice fields and rising sea levels, from shifting weather patterns that contribute to flooding and drought, and increasing numbers and intensities of extreme weather events (Strain and Cure, 1985, Meier 1985). Human activity is one of the main causes of increased CO_2 and other greenhouse gases. It should, therefore, be possible to reduce the human contribution to CO_2 buildup and the greenhouse effect associated with atmospheric warming.

The increase in atmospheric CO_2 can be slowed by retaining the C that is captured by plant photosynthesis. Organic matter in soil is a natural reservoir for organic C. Unfortunately, some agricultural practices do not preserve soil organic matter. Conservation tillage practices that keep residues on the soil surface and utilization of cover crops, crop rotations, and organic amendments, usually maintain or increase the soil organic matter reservoir (Rasmussen and Parton, 1994).

If we as a nation are to contribute to a global effort to slow the increase of atmospheric CO_2, it will be necessary to determine the amount of C that can be sequestered by any method. Production agriculture, by adopting appropriate management systems, can contribute to C sequestration. There is an immediate need for a tool that will estimate how selected management systems will effect organic C storage in soils. These estimates could be provided by a field-level, C-sequestration model that is sensitive to local soils, climate, crop and tillage management systems, crop rotations, fertilization, cover crops, and organic amendments (Berc, 1999). It is highly desirable that this model operate in the field utilizing readily accessible data sets. This model can be applied to assist farm-planning efforts to enhance C sequestration. It can also be added to national, resource-inventory protocols to track regional and national scale soil-C stocks. Such a tool can help policy and program development for C sequestration just as soil-loss equations have been used to develop and evaluate erosion-control policies.

Objective

Staff of the Agricultural Research Service (ARS) at the Pendleton Research Center have been developing a C sequestration model named "CQESTR" that will compute the decomposition rate and residence time-in-the-soil of C from antecedent organic matter, crop residues, crop roots, and organic C-containing amendments such as compost, manure, sewage sludge, or other biosolids.

Methods

The core of the model was the residue decomposition model "D3R" (Douglas and Rickman, 1992). The D3R model used air temperature and residue N content as the primary controller of decomposition rate. Residue location above or below the soil surface, as determined by tillage practices, provided an index for the effect of water on rate of decomposition. Decomposition computations by D3R have been compared and found to accurately predict the decomposition of residues from data sets for a variety of crops from Alaska; Washington; Oregon; Idaho; Missouri; Indiana; North Carolina; Georgia; Texas; Colorado, Saskatchewan, Canada; and Uppsula, Sweden (laboratory study) (Curtin et al., 1998; Douglas and Rickman, 1992; Moulin and Beckie, 1993, 1994).

Microbes convert the majority of residue and organic C added to a soil to CO_2. A small fraction of residues is consumed by worms, insects, and small mammals. This nonmicrobial consumption will depend strongly on climate, the kind and mass of surface residue present, the length of time residue has been on the soil surface, and the local population of soil fauna. Predicting this consumption would be an independent modeling project that was not attempted in CQESTR. If this fraction was known to be locally significant, relative to microbial oxidation, it should be subtracted from the residue mass input to CQESTR. Physical removal of organic matter and residue from a field by wind or water erosion was not computed by CQESTR. Grazing or mechanical removal of a fraction of harvested residue was also assumed to be accounted for in the values of residue mass provided as input to CQESTR.

Much of the information required by CQESTR can be obtained nationally from existing data files that have been created for the use in the Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE). The N content of residues may be obtained from local information, values published in the literature, or existing compilations of plant nutrient content, such as the database "CPIDS" developed for the Water Erosion Prediction Project (WEPP) or the FAO Tropical Feeds database. The FAO database is available on the internet at www.fao.org/WAICENT/FAOINFO/AGRICULT/AGA/AGAP/FRG/TFEED8/index.htm
It lists crude, protein content of hundreds of plant species produced under a wide variety of growing conditions. Nitrogen content for crop residues can be calculated using the N content for protein of 16 percent. Soil organic matter content by layer, and layer depths, can be obtained from the national soil surveys (available from the MUIR database) and local Natural Resources Conservation Service (NRCS) offices. Root distributions may be determined from an exponential decay-with-depth relationship that will depend upon crop type and local climate (Belford et al., 1987; Gerwitz and Page, 1974).

One requirement for validation of CQESTR has been to compare the predicted decomposition rate for antecedent soil organic matter to observed values. Another requirement was to verify the conversion rate of the very slowly decomposing fraction of added residues into soil organic matter.

Observations for these two factors will be obtained from long-term soil organic matter data, for management treatments with differing amounts and types of residue added. These data were available from the long-term management plots on the Pendleton Research Center and from other U.S. and international, long-term management experiments. Many of these data sets are available from the Soil Organic Matter Network (SOMNET) of the Global Change and Terrestrial Ecosystems (GCTE) project of the International Geosphere-Biosphere Programme. Scientists at the Pendleton location are fully contributing members of SOMNET.

Results

CQESTR will compute C sequestration in the soil of a field as affected by climate, soil, crop production, and management practices used in that field. The amount of C stored and the time to equilibrium of C content will be provided using a "windows" format computer program that allowed point-and-click selection of most input data. It will also allow construction of batch files for runs of multiple sites and management scenarios. The program's output will include, for all rotations and management options requested, both short- and long-term trends of surface and buried residues, and changes in the soil organic matter content.

References

Belford, B., B. Klepper, and R.W. Rickman. 1987. Studies of intact shoot-root systems of field-grown winter wheat. II. Root and shoot developmental patterns as related to nitrogen fertilizer. Agron. J. 79:310–319.

Berc, J. L. 1999. NRCS roles and needs. Presented at the USDA-ARS workshop on soil carbon, Baltimore MD, January 12-14, 1999. Personal communication.

Curtin, D., F. Selles, H. Wang, C.A. Campbell, and V.O. Biederbeck. 1998. Carbon dioxide emissions and transformations of soil carbon and nitrogen during wheat straw decomposition. Soil Sci. Soc. Am. J. 62:1035–1041.

Doos, B.R. 1975 The physical basis of climate and climate modelling. Report of the International Study Conference in Stockholm, 29 July - 10 August 1974. GARP Publications Series No. 16., WMO, Geneva, Switzerland.

Douglas, C.L., Jr., and R.W. Rickman. 1992. Estimating crop residue decomposition from air temperature, initial nitrogen content, and residue placement. Soil Sci. Soc. Am. J. 56:272–278.

Gerwitz, A., and E.R. Page. 1974. An empirical mathematical model to describe plant root systems. J. Appl. Ecol. 11:773–782.

Jones, P.D., and K.R. Briffa. 1992. Global surface air temperature variations during the twentieth century: Part 1, spatial, temporal and seasonal details. The Holocene 2:165–79.

Keeling, C.D., and T.P. Whorf. 1994. Atmospheric carbon dioxide records from sites in the SIO air sampling network. p. 16–26. *In* T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (ed.) Trends '93: A compendium of data on global change. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, TN, U.S.A.

Meier, Mark F. 1985. Glaciers, ice sheets, and sea level: Effect of a CO_2 -induced climatic change. Report of a workshop held in Seattle, Washington September 13-15, 1984. DOE/ER/60235-1.,NTIS, US Dept. of Commerce, Springfield VA.

Moulin, A.P., and H.J. Beckie. 1993. Predicting crop residue decomposition. p. 104–109. *In* Proc. Sask. Soils and Crops Workshop.

Moulin, A.P., and H.J. Beckie. 1994. Predicting crop residue in cropping systems. p. 7–14. *In* Proc. Sask. Soils and Crops Workshop. Personal communication.

Rasmussen, P.E., and W.J. Parton. 1994. Long-term effects of residue management in wheat-fallow: I. Inputs, yield, and soil organic matter. Soil Sci. Soc. Am. J. 58:523–530.

Strain, B.R., J.D. Cure. 1985. Direct effects of increasing carbon dioxide on vegetation. DOE/ER-0238., NTIS, US Dept. of Commerce, Springfield VA.